Corrosion of materials used as cutting tools of wood

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Abstract

According to the wood species and the type of metallic materials, the wear of woodcutting tools is very different. The metallic nature of cutting tools, the water and water-soluble components in the wood result in an electrochemical mechanism of corrosion. Of course, both a mechanical wear and an electrochemical action are responsible of the total wear of metallic tools. The objective of this study is to characterise the electrochemical action of the wood medium on the corrosion of the woodcutting tool materials.

To carry out the corrosion tests, a corrosive medium is obtained by infusing wood shavings into water to obtain a juice of wood. In a second step, we have selected several metallic materials used in woodcutting and a wood specie, namely oak. Electrochemical measurements (R_p, E_{corr} and $i = f(E)$ curve) were carried out during 24 h in a medium containing a water-soluble extract of oak (=an oak juice). The electrochemical behaviour of each metallic material was characterised and the morphology of the corroded surface was observed by SEM. It is shown that the electrochemical corrosion is not negligible and can be very important on cutting materials. Further experiments are in progress to characterise the effect of the mechanical wear by tribocorrosion measurements.

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1. Introduction

The industry of wood has a poor knowledge of the degradation phenomenon of tools in contact with wood. The large number of parameters related to the machining of different wood materials hinders the prediction of the evolution of the wear of tools. According to the literature, different wear profiles of sharpened edge were reported that cannot be explained by differences in mechanical properties of the wood or the machining parameters [1].

So both mechanical and corrosive mechanisms are responsible of the wear of wood cutting tools [2,3]. The determination of the relative magnitude of each mechanism is a challenge for the wood industry attempting to improve and to adapt the quality of cutting tools.

For example, the machining of a wood known as "acid" like oak generally generates a tool wear greater than the machining of a wood having a pH close to 7 like fir. The wood moisture and the multi-component nature of cutting tools also play an important role in the kinetics of tools degradation [4].

The objective of this preliminary study is to characterise the electrochemical part of the degradation of the tools in contact with a wood medium prepared from oak. The wood medium named wood juice was prepared by infusing wood shavings in distilled water to concentrate the soluble parts (minerals salts, organic acids as acetic and formic acids, and soluble tannins) in an aqueous medium. The investigation was focused on the corrosion behaviour of several metallic materials used as cutting materials in the juice of oak, by using electrochemical methods and surface observations. Two types of materials were used, namely carbon steels and tungsten carbide-based alloys.

2. Materials and methods

Electrochemical tests were performed in a three-electrode electrochemical cell connected to an EGG PAR 273A potentiostat and driven by a computer. A circular and horizontal working electrode (2.8 cm^2) was placed at the bottom of the cell

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Table 1
Composition of carbon steel materials

Material	Composition (at%)								
	Mo	V	C	Cr	Mn	Fe	Co	Ni	Si
Steel 1	0.13	0.07	15.98	6.10	0.31	76.16	0.10	0.29	0.80
Steel 2	0.23	1.11	11.75	2.54	0.24	81.61	0.90	0.18	1.35
Steel 3	0.12	0.05	11.17	1.73	0.35	83.86	0	2.25	0.55

under a Pt-disk electrode. The reference electrode was a KCl-saturated calomel electrode (Hg/Hg$_2$Cl$_2$, $E = +0.242$ V/SHE), and all working electrode potentials are given versus this reference electrode. The working electrode was mechanically polished with successively finer grades of SiC emery paper, then with colloidal silica dispersed in water (particle size 0.1 μm). Samples were finally rinsed with distilled water, ethanol and dried. All the experiments were performed in aerated conditions.

The following experimental sequence was used. The measurements of the corrosion potential, E_{corr}, and the polarisation resistance, R_p, were done every 2 h during 24 h at a scan rate of 0.166 mV/s between $E_{corr} \pm 20$ mV. Potentiodynamic curves were recorded from −250 to +800 mV versus E_{corr} at a sweep rate of 1 mV/s.

To prepare the wood medium representative of the corrosive conditions, a protocol generally admitted by the wood research community, was used [5,6]. The procedure started with crushing oak in small plates of 5 mm × 1 mm × 1 mm size in a board of oak directed in the longitudinal direction and with a moisture of 12%. These plates were finely ground in 0.1 mm parts, and then infused in distilled water during 1 week in a closed container that was stirred regularly. The mass composition of the melt is 1/10 of wood and 9/10 of water. Two kilograms of wood shavings is necessary to produce 20 l of the "wood juice". After that, the infused brownish liquid was filtered. The pH of the wood juice is 4.5.

The compositions of the tested steel (Aubert & Duval Holding) are given in Table 1. Metallographic analyses revealed the presence of numerous carbide, mainly chromium, silicium and vanadium carbide (Figs. 1 and 2). In fact the major parts of these elements are present as carbides in these alloys. In opposition, WC-based alloys made by powder sintering present a compact network of tungsten carbide with a metallic binder (Fig. 1). The amount of binder and the composition are listed in Table 2.

To observe the corrosion profile, the samples were immersed in the wood juice during 10 days. After this immersion, the oxidised samples were pickled to remove the corrosion layer in view of a SEM investigation. Metallographic cross-sections

Table 2
Composition of WC-based materials

Material	WC (wt%)	Binder (wt%)	Composition of binder (at%)		
			Co	Ni	Cr
MG 18	90	10	98.5	1.5	0
KCR 05	97.3	2.7	80	9	11
KCR 06	97	3	88	9	3
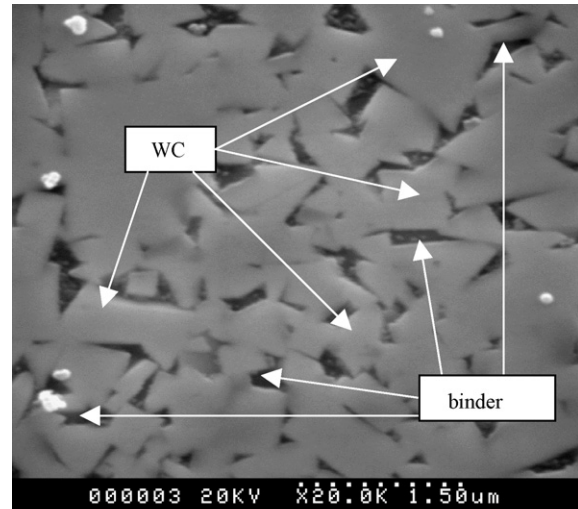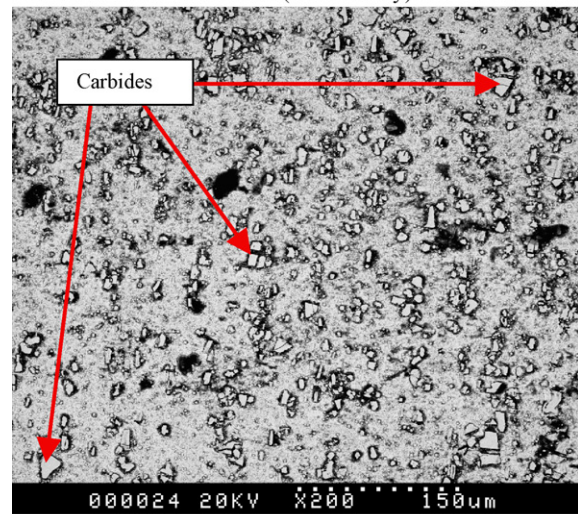
Fig. 1. SEM of WC-based MG 18 alloy and carbon steel Steel 1 alloy investigated.

were prepared by polishing with successively finer grades of SiC emery paper, and then with colloidal silica dispersed in water (particle size 0.1 μm).

3. Results

3.1. Corrosion behaviour of tungsten carbide-based alloys

The MG 18 alloy is among the WC-based alloys tested the less corrosion resistant in the wood juice (Fig. 3). Indeed, the R_p values of MG 18 is two times lower than the R_p of the KCR alloys, and the corrosion potential after 1 day of immersion is 100 mV lower than the others after 20 h of immersion.

The E_{corr} and I_{corr} values for the WC alloys are reported in Table 3 and Fig. 4. All the alloys exhibit a small passivation plateau. The most resistant corrosion layer is developed by the KCR 05 alloy, whereas the MG 18 alloy rapidly suffers from pitting from −50 mV/SCE on with a current of about 10^{-3} A/cm^2 at +100 mV/SCE.
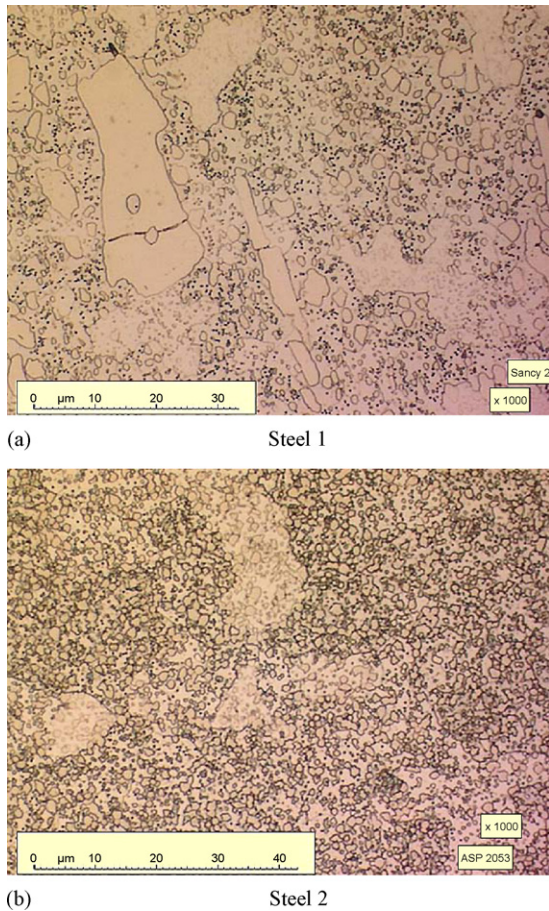
(a) Steel 1

(b) Steel 2

Fig. 2. Optical metallography of: (a) Steel 1 and (b) Steel 2.

From Fig. 5, it can note that the metallic binder of the WC alloys is the main constituent affected by corrosion in the wood juice. Indeed, the corroded part is very porous and mainly constituted by a network of WC grains.

3.2. Corrosion behaviour of carbon steels

Steel 1 has a higher R_p than Steels 2 and 3 in the wood juice in function of immersion time (Fig. 6). In addition, the variation of R_p values for Steel 1 can be correlated to the potential variation of Steel 1 indicating a difficulty to achieve a stable passive state. However, despite the variation of the E_{corr} values, the potential of Steel 1 is 200 mV higher than the one for the other steels. The E_{corr} and I_{corr} values are summarised in Table 3.

Fig. 7 confirms that the corrosive layer on Steel 1 alloy is the most resistant up to about −100 mV/SCE with a passive current
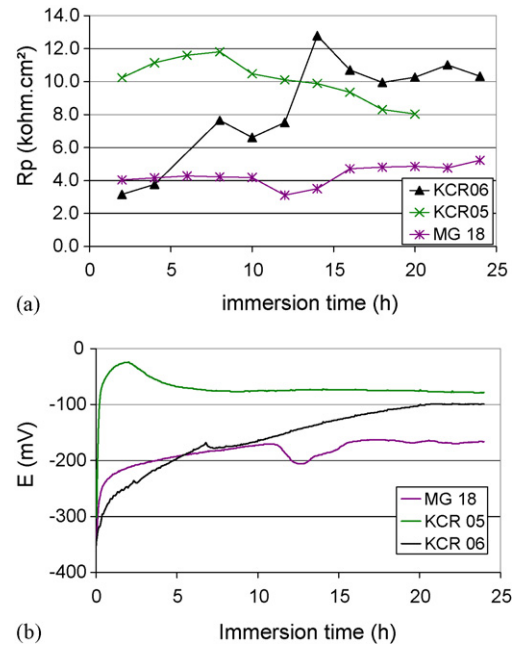

Fig. 3. Evolution of: (a) R_p and E_{corr} (in mV/SCE) and (b) WC–Co alloys in wood juice during an immersion of 24 h.
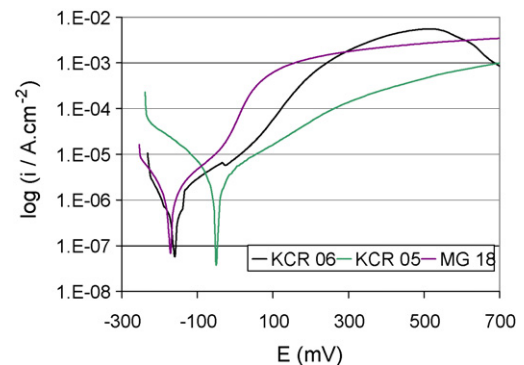

Fig. 4. Potentiodynamic polarisation curves of WC materials in wood juice after 24 h of immersion (potential in mV/SCE).

of 10^{-5} A/cm^2 (at −300 mV/SCE). On the contrary, Steel 2 alloy dissolves over the whole potential range. Concerning Steel 3 alloy, a low passive state without pitting even at a high potential is noticed.

The metallographic structure of the two steels is shown in Fig. 2. In the case of Steel 2 with a low 11 at% carbon content, a dense and homogeneous distribution of carbide is noticed (Fig. 2b). This network of fine carbide forms a porous layer at the

Table 3
E_{corr} and I_{corr} values after 24 h of immersion

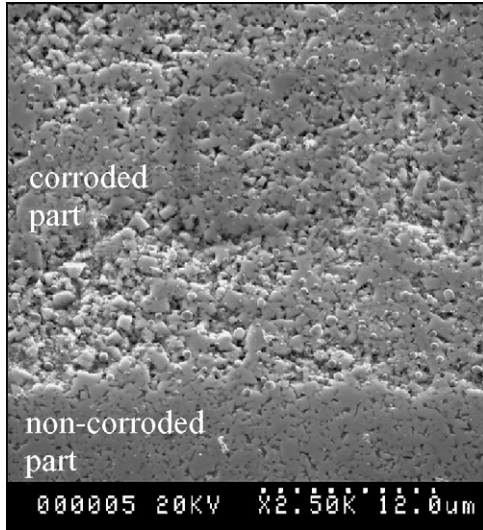|	Material					
	Steel 1	Steel 2	Steel 3	MG 18	KCR 05	KCR 06
E_{corr} (mV/SCE)	−466	−666	−667	−172	−43.5	−161
I_{corr} (µA)	1.70	14.80	4.41	4.19	3.12	2.05

Fig. 5. Metallographic cross-section of the WC–Co material (MG 18) after immersion for 24 h in wood juice.

surface of the steels after immersion in the wood juice (Fig. 8b). In contrast, Steel 1 contains a high concentration of carbon and a distribution of carbide which is much more heterogeneous with some large precipitates of carbide with a size of several tens of micrometers, and a more diluted distribution of small carbides (Fig. 2a). After the immersion in the wood juice and the corrosion of the steel matrix, only large carbides are present on the surface (Fig. 8a).
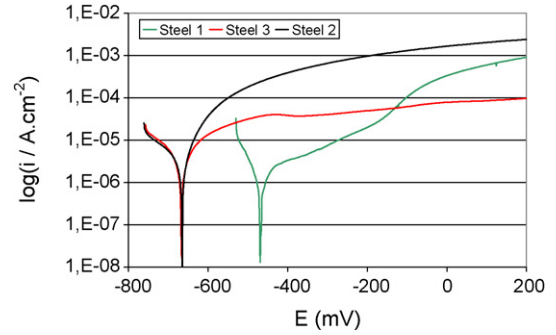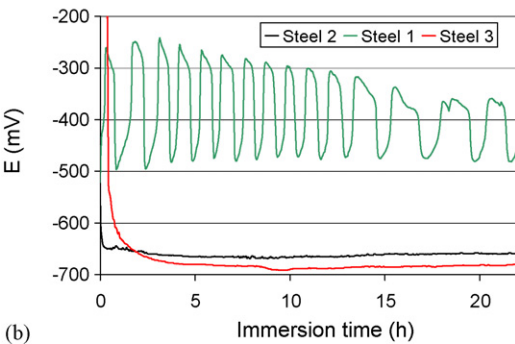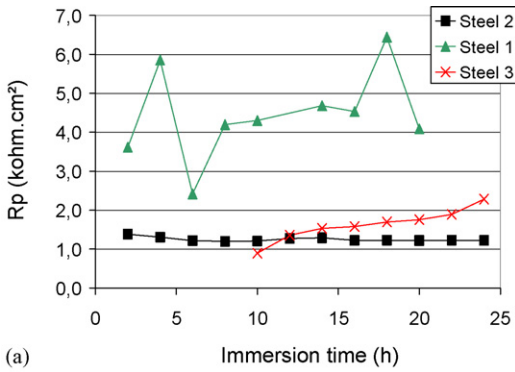

Fig. 6. Evolution of: (a) R_p and (b) E_{corr} (mV/SCE) for carbon steels during 24 h of immersion in wood juice.

Fig. 7. Potentiodynamic polarisation curves of carbon steels recorded in wood juice after immersion for 24 h.
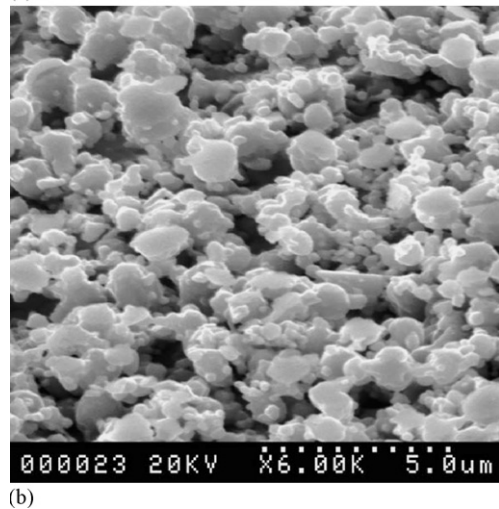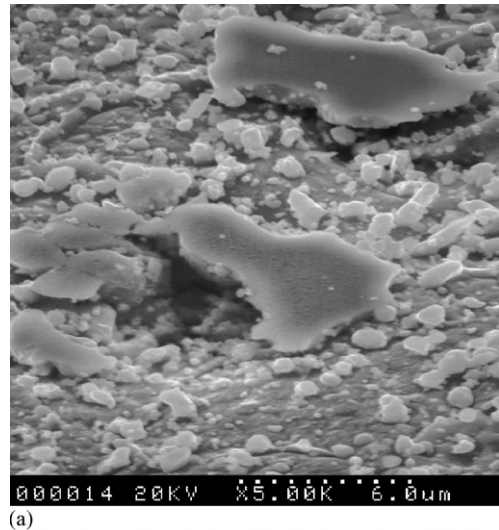

Fig. 8. SEM of: (a) Steel 1 and (b) Steel 2 after 10 days of immersion in wood juice and after dissolution of the corrosion products.

4. Discussion and conclusion

The preliminary results obtained in this study indicate that the soluble part of the wood is not inert with respect to the wood cutting materials. This confirms that a subsequent part of the wear observed on cutting tools is due to corrosion of metals in contact with wood. For WC-based alloys, since the electro-

chemical part of these alloys is the Co(Ni, Cr) metallic binder, the lower the binder concentration is, the higher the corrosion resistance is. So it is obvious that WC-based alloys containing a small amount of metallic binder, namely the KCR alloys, present a better corrosion resistance compared to the MG 18 alloys with a 10% of binder. Indeed for a same area, the metallic active surface depends on the metallic binder content. However, for a same binder concentration (see KCR 05 and KCR 06), the chromium content seems to be the main factor determining the dissolution rate of the binder and the stability of the formed passive layer.

For carbon steels, the results demonstrate that the alloy containing the highest chromium concentration, namely Steel 1, has the lowest corrosion rate and the highest corrosion potential in the wood juice.

The behaviour of Steel 1 can be compared to the one of Steel 3 that contains a low chromium content and a high nickel content. Indeed, Steel 3 has a stable passivation plateau over the whole potential range, but the passivation current is relatively high at 5×10^{-4} A/cm^2. Thus, a high nickel concentration seems to stabilise the passive layer and allows a good protection against pitting in the wood juice. For Steel 2 that contains the lowest chromium and nickel concentrations, the corrosion behaviour is the worst one with no passivation plateau in the wood juice.

In all cases, the matrix is preferentially corroded which has the effect to expose the carbides. After dissolution of the corrosion products, it appears that the attack is stronger in zones close to the carbides, which are affected by a classical chromium depletion effect.

For the cutting tools application, the dissolution of the matrix inducing the carbide exposition in the wood juice is an important phenomenon. Indeed, the corrosion processes allow taking out more easily the carbides from the metallic matrix under the effect of abrasion. Consequently, the mechanical resistance of cutting materials such as WC-based alloys or carbides and carbon steels used in the industry of wood drastically decrease when corrosive agents of wood dissolve the metallic matrix. In practice, one can suggest that the wear of cutting tools is due to combined corrosion/abrasion steps, which may lead to the complete degradation of the materials.

In conclusion, the corrosion behaviour of carbon steels in wood juice is mainly determined by the nickel and chromium contents in the alloys. Nickel allows to limit the pitting effect, and chromium allows to decrease the current in the passive region. For WC alloys, the composition and the amount of binder are the two factors determining the corrosion resistance in the wood juice.

Acknowledgements

References

[1] A. Chardin, Etude de l'usure des dents de scies, vols. 1 and 2, Centre Technique Forestier Tropical, 1966.
[2] G.B. Mohan, B.E. Klamecki, Wear 74 (1) (1981) 85–92.
[3] J. Rueckert, Werkstoffe und Korrosion 37 (6) (1986) 336–339.
[4] F. Eyma, Caractérisation des efforts de coupe de différentes essences de bois à l'aide de leurs paramètres mécaniques, Ph.D. Thesis, Université Henri Poincaré, Nancy 1, France, 2002.
[5] R.V. Subrmanian, K.N. Somasekharan, W.E. Johns, Holzforschung (1983) 117–120.
[6] M. Ziomek-Moroz, Corrosion 50 (4) (1994) 276–278.